

Simulated Lunar Environment For The Study Of Regolith Strength: An Improved Vacuum Bevometer Design

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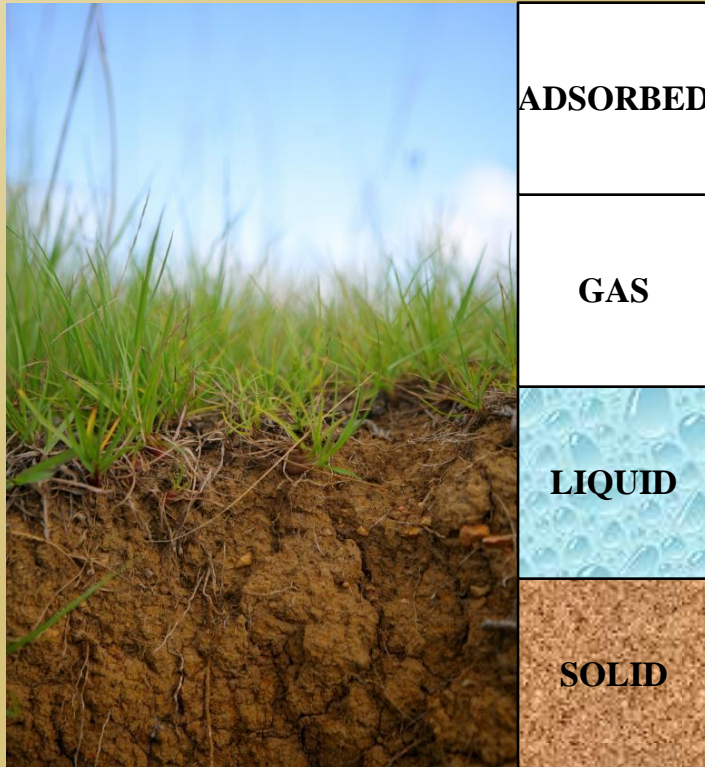
March 6th, 2012

Presentation Outline

- Introduction
- Objective, Scope, Assumptions
- Experimental Setup
- Initial Results
- Improved Design
- Summary and Conclusions
- Continued Work

Terrestrial Soil Vs. Lunar Soil

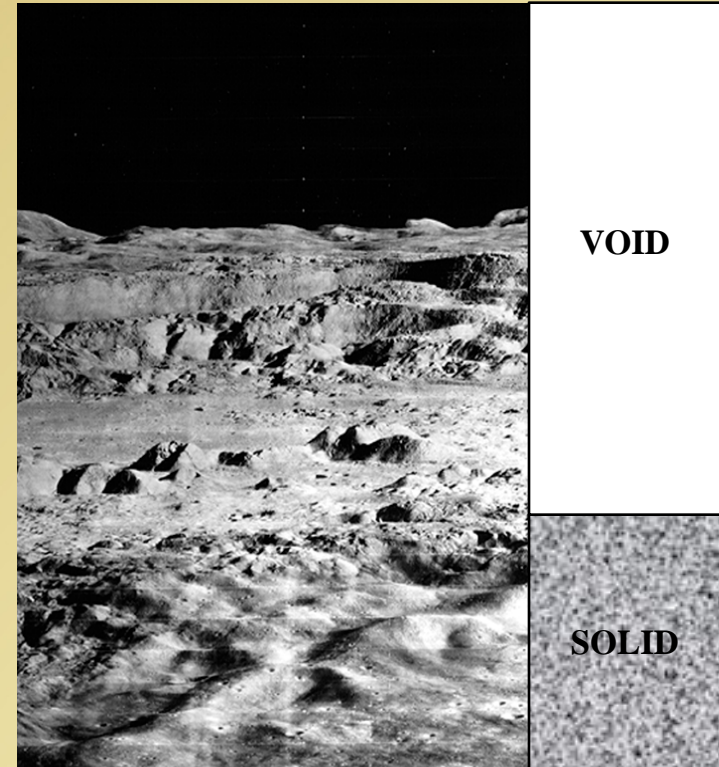
Multi-Phase Soil Model



- Atmosphere
- 760 torr pressure
- Flowing water
- -89 to 58°C temperatures

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Non-Terrestrial Soil Model



- Sparse atmosphere
- 10^{-12} to 10^{-8} torr pressure
- Lack of flowing water
- -171 to 111°C temperatures
- Space weathering
 - Meteoroid bombardments
 - Ionizing radiation

Motivation

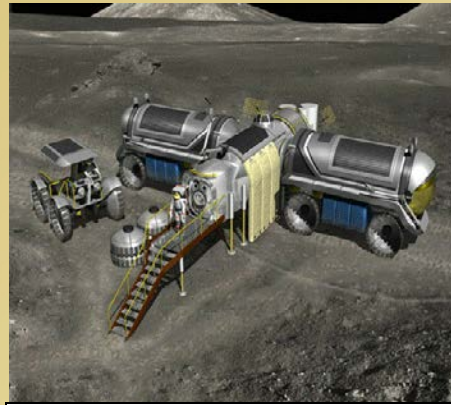
Meet the growing need for a more comprehensive understanding of the strength properties of the lunar regolith.

- Previous missions do not provide sufficient information for unexplored regions.
- Simulants match composition in specific regions, not necessarily terrain strength.



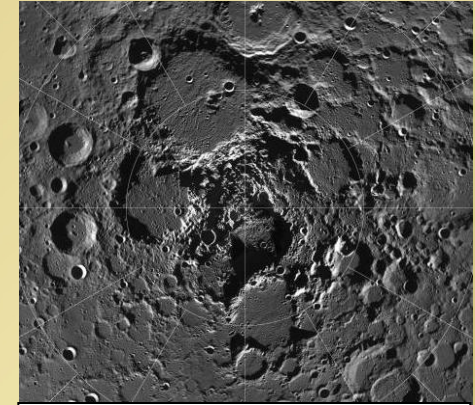
SIMULATION

Simulate parameters of the lunar environment that likely contribute to regolith strength.



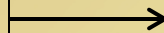
TESTING/ANALYSIS

Instrument chamber to perform soil tests to understand the effects on soil strength.



EXTRAPOLATION

Interpret the strength of lunar soil in previously unexplored regions.



Objectives, Scope, Assumptions

Objective:

- Develop a lunar environmental simulation chamber for the evaluation of soil deformation under surface loading.

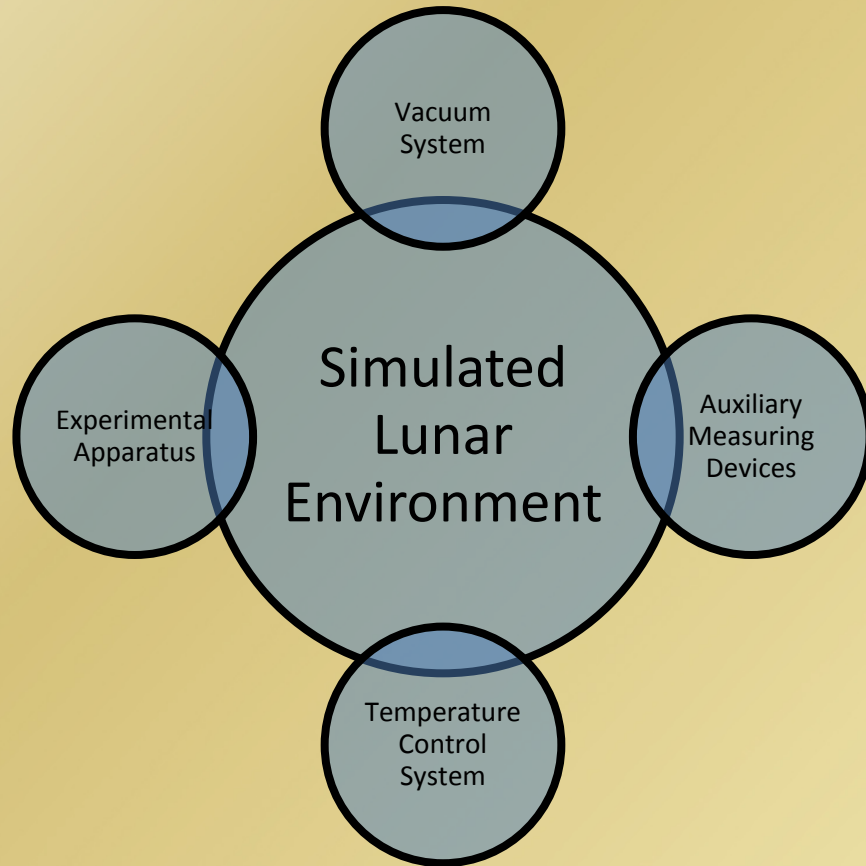
Scope:

- Vacuum and temperature ranges to represent the Moon's surface.
- Chamber chosen to be relatively small to minimize vacuum pump down time.
- Prepare lunar soil simulants to known density, under vacuum conditions, and in a repeatable fashion.
- Capable of implementing bevameter type plate load-sinkage, annular shear, and cone penetration tests
- Gravity effects to be accounted for by applying similitude scaling laws (Langhaar, 1964).

Assumptions:

- Lunar simulant under lunar density, vacuum, and temperature conditions will deform similarly to lunar soil when loaded according to similitude scaling laws.

Experimental Test System



Vacuum System:

- Roughing pump
- Turbomolecular pump
- Thermocouple pressure sensors
- Cold cathode ion pressure sensor

Bevameter System:

- Soil hopper
- Copper Soil bin
- Sample manipulator
- Quartz heat lamp
- Copper cooling plate
- Thermocouple temperature sensor
- Combined torque/thrust cell
- External drive mechanism

Experimental Apparatus

To bevameter superstructure

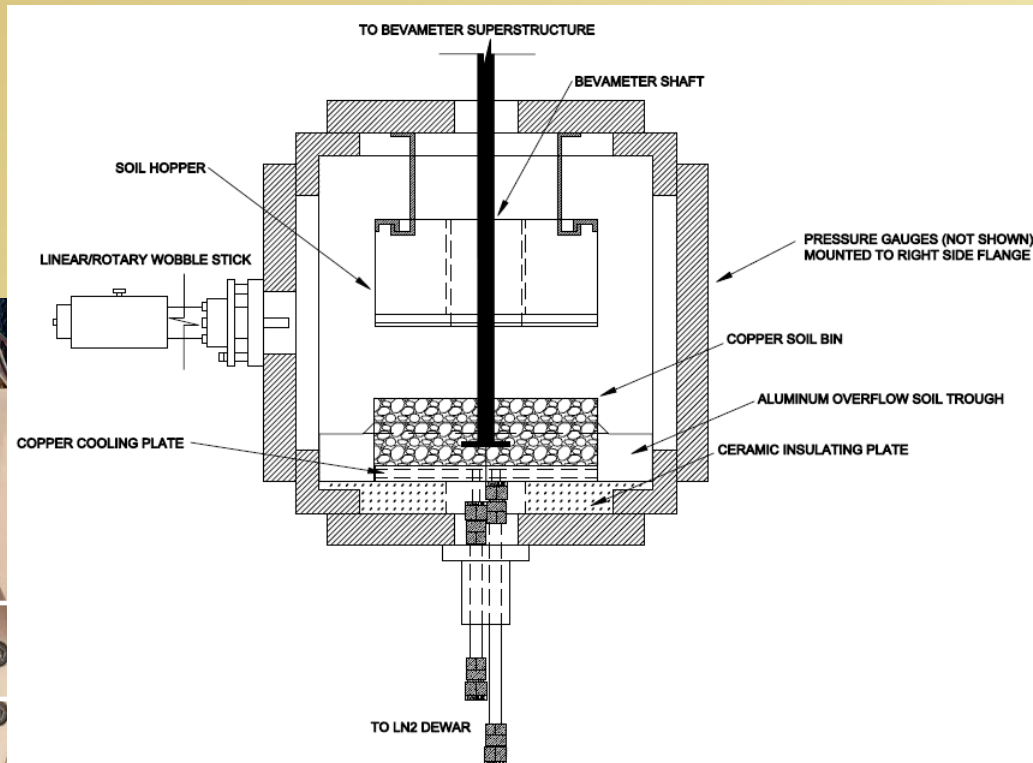
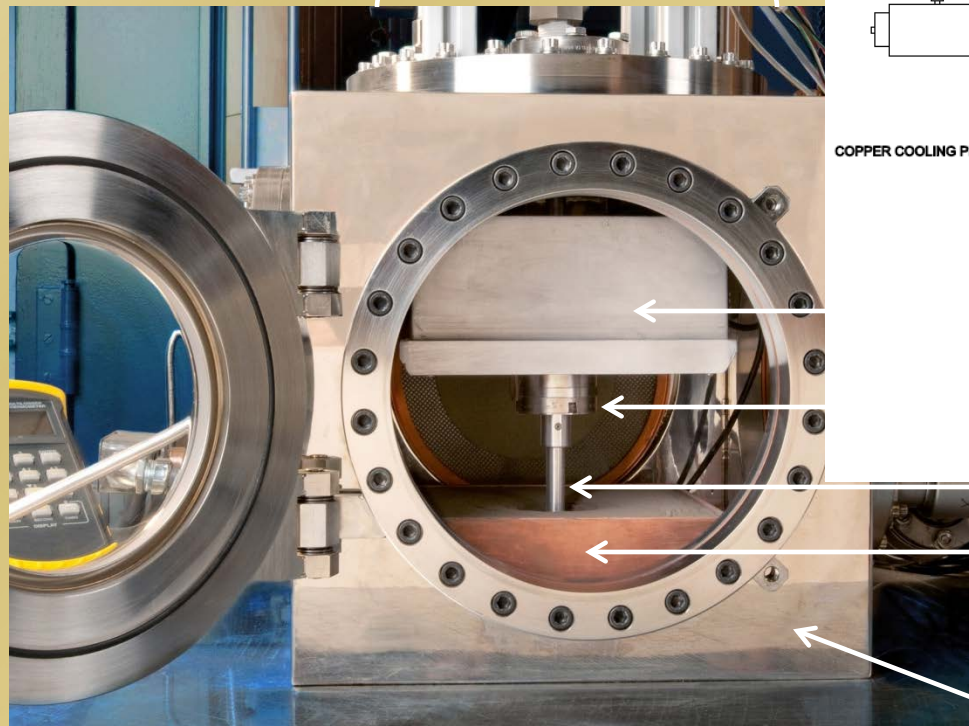


Plate-sinkage end effector

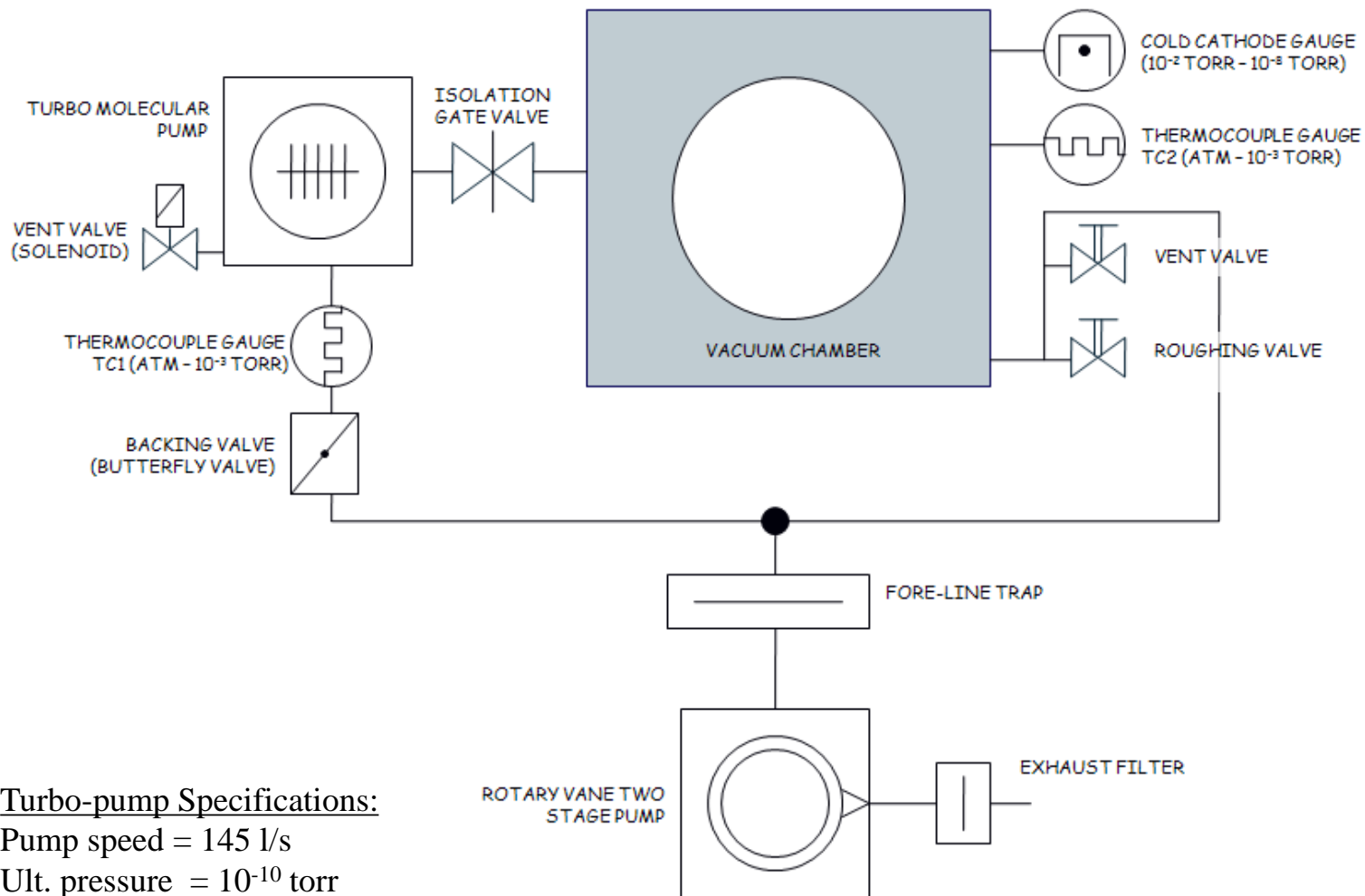
Copper soil bin

Vacuum chamber:

Total volume = 23 liters

Surface area = 5000 cm²

Vacuum Pumping System

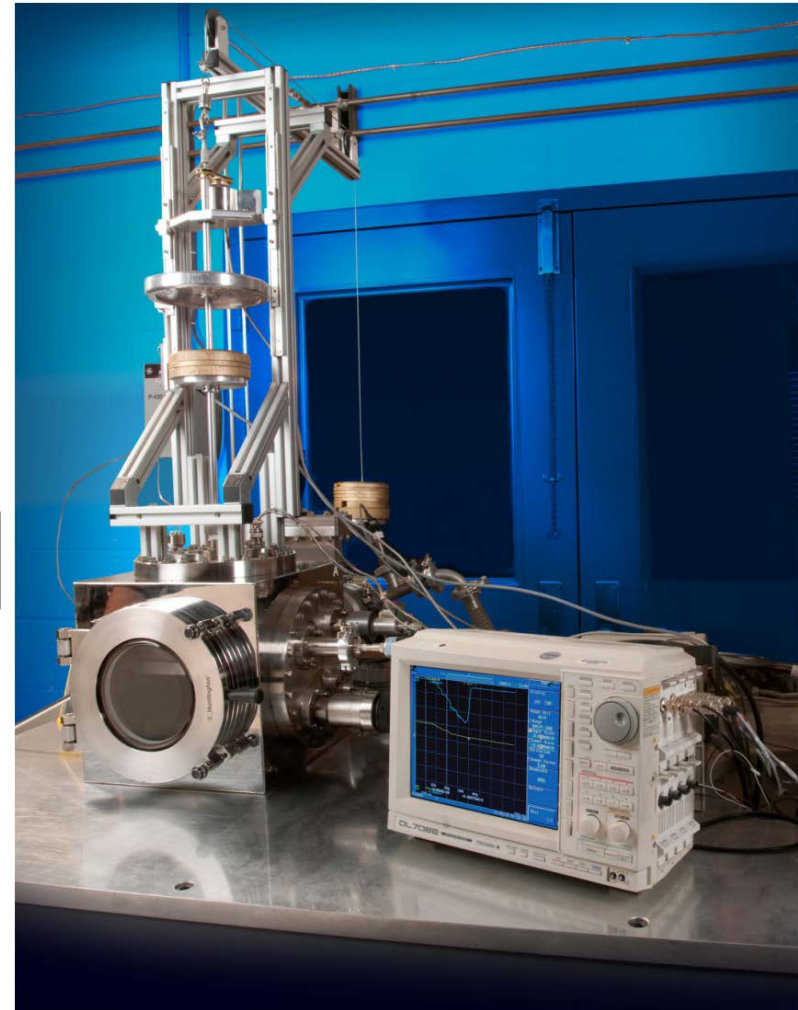
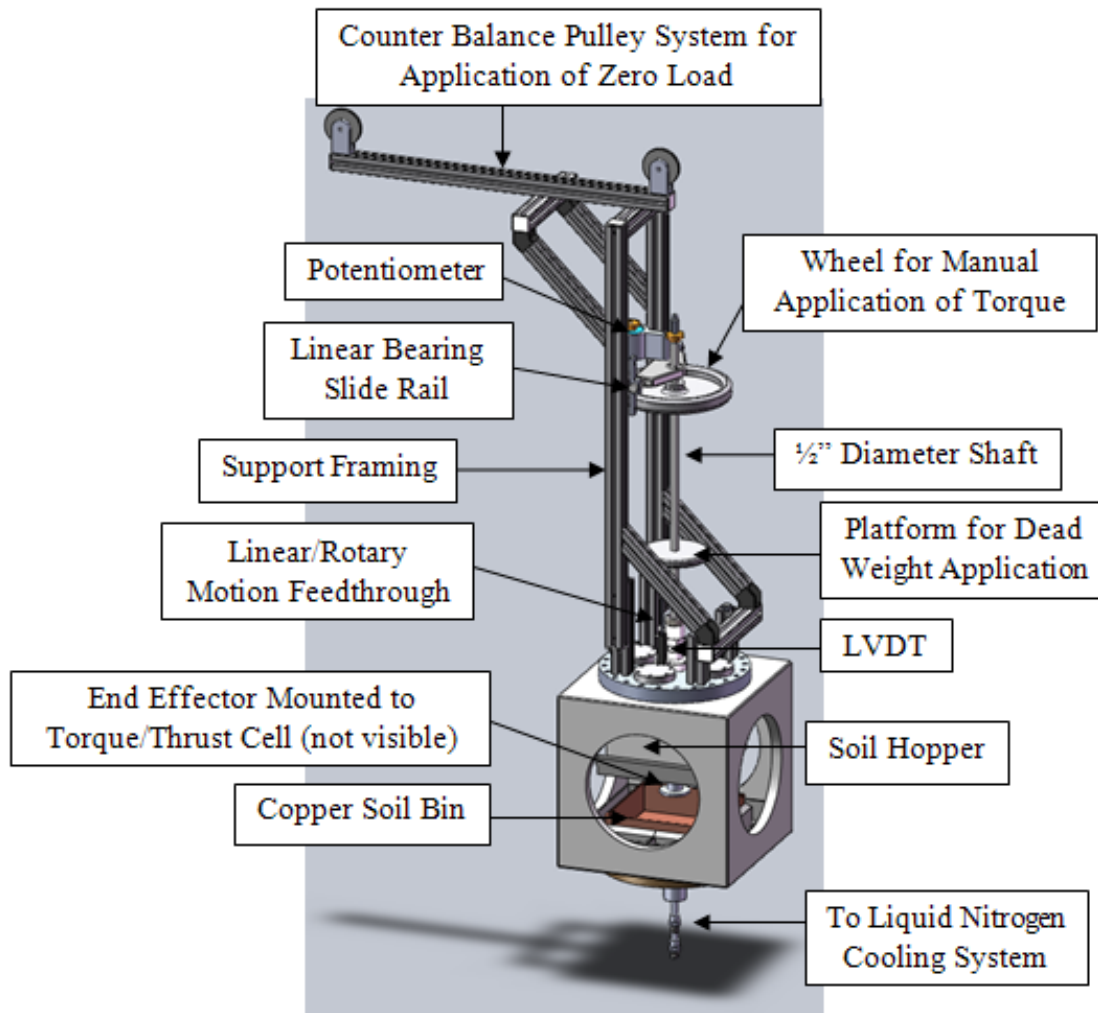


Turbo-pump Specifications:

Pump speed = 145 l/s

Ult. pressure = 10^{-10} torr

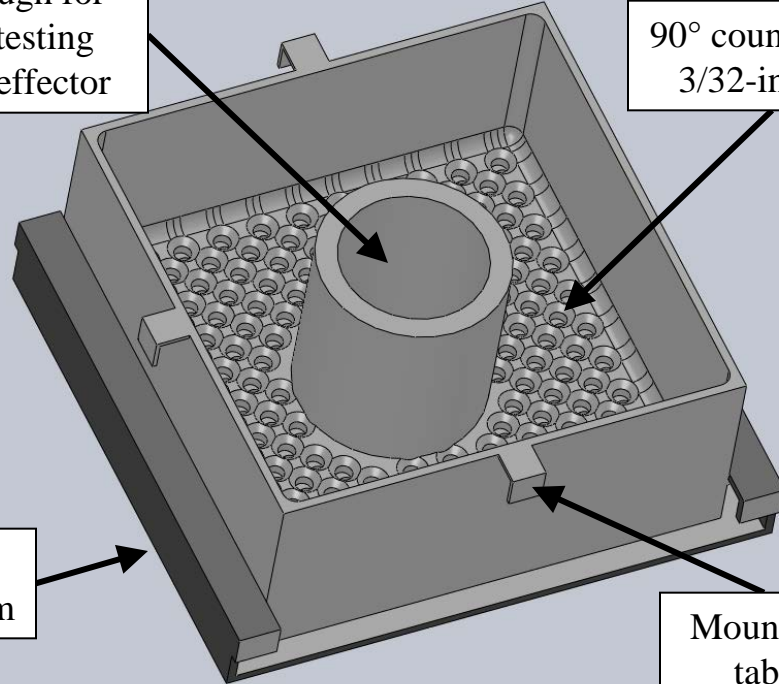
Strength Testing – System Overview



Strength Testing Soil Preparation

Feed through for strength testing shaft/end effector

90° countersunk 3/32-in. grid



Sliding Mechanism

Mounting tabs

Soil Preparation:

1. Simulant placed in hopper
2. 5 micron mesh placed over hopper
3. Hopper mounted in vacuum chamber
4. Vacuum pulled to desired test pressure
5. Sliding mechanism moved to open position
6. Soil “rains” down into copper sample bin
7. Soil leveled
8. End effector lowered to soil surface
9. Soil strength test performed



**Simulant
Outgassing**

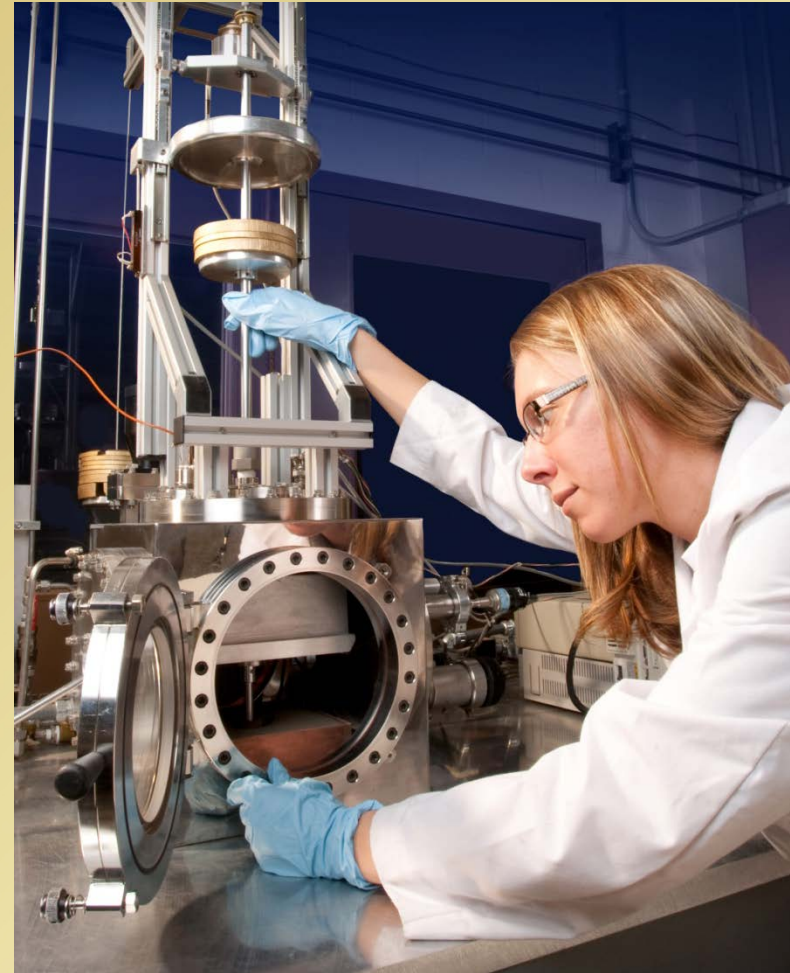


**Strength
Testing**

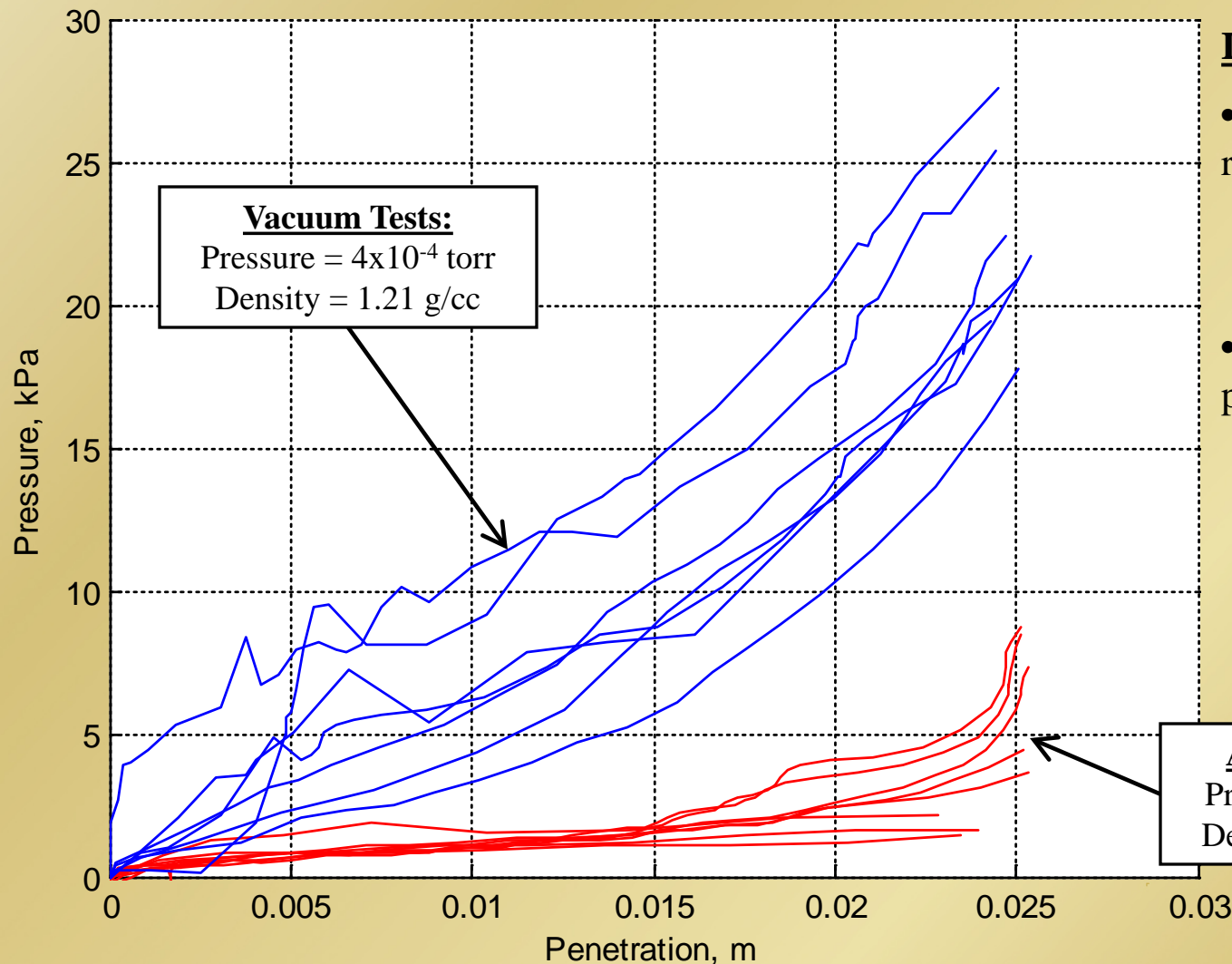
Experimental Testing

Preliminary Tests:

- Plate load-sinkage experiments
- 32 mm diameter plate
(190 mm plate on Moon)
- Air-dried JSC-1A lunar simulant
- Earth-ambient conditions
- High vacuum conditions
(8.5 to 4.9×10^{-4} torr)
- Room temperature
(24°C , 36% humidity)



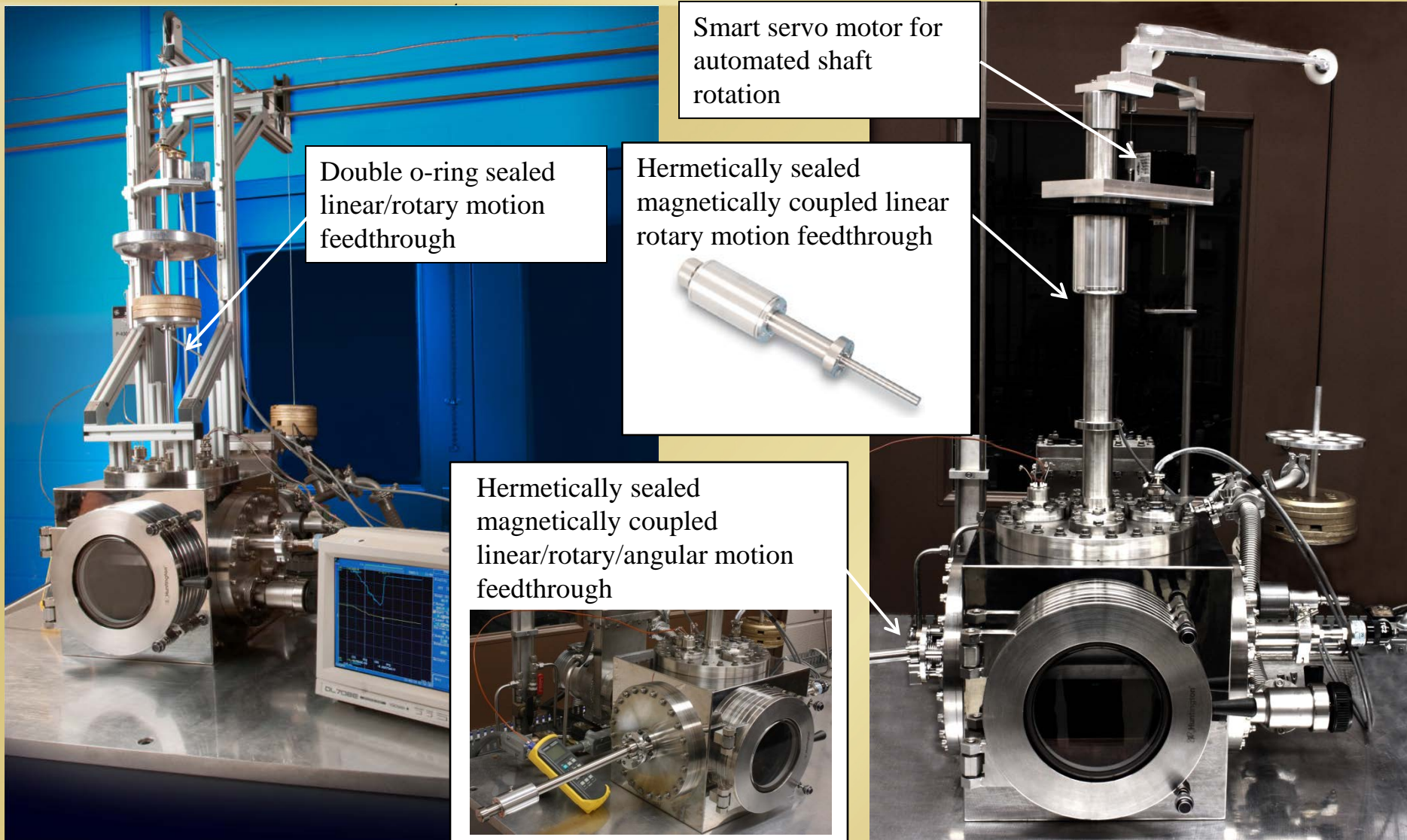
Preliminary Plate-Sinkage Results



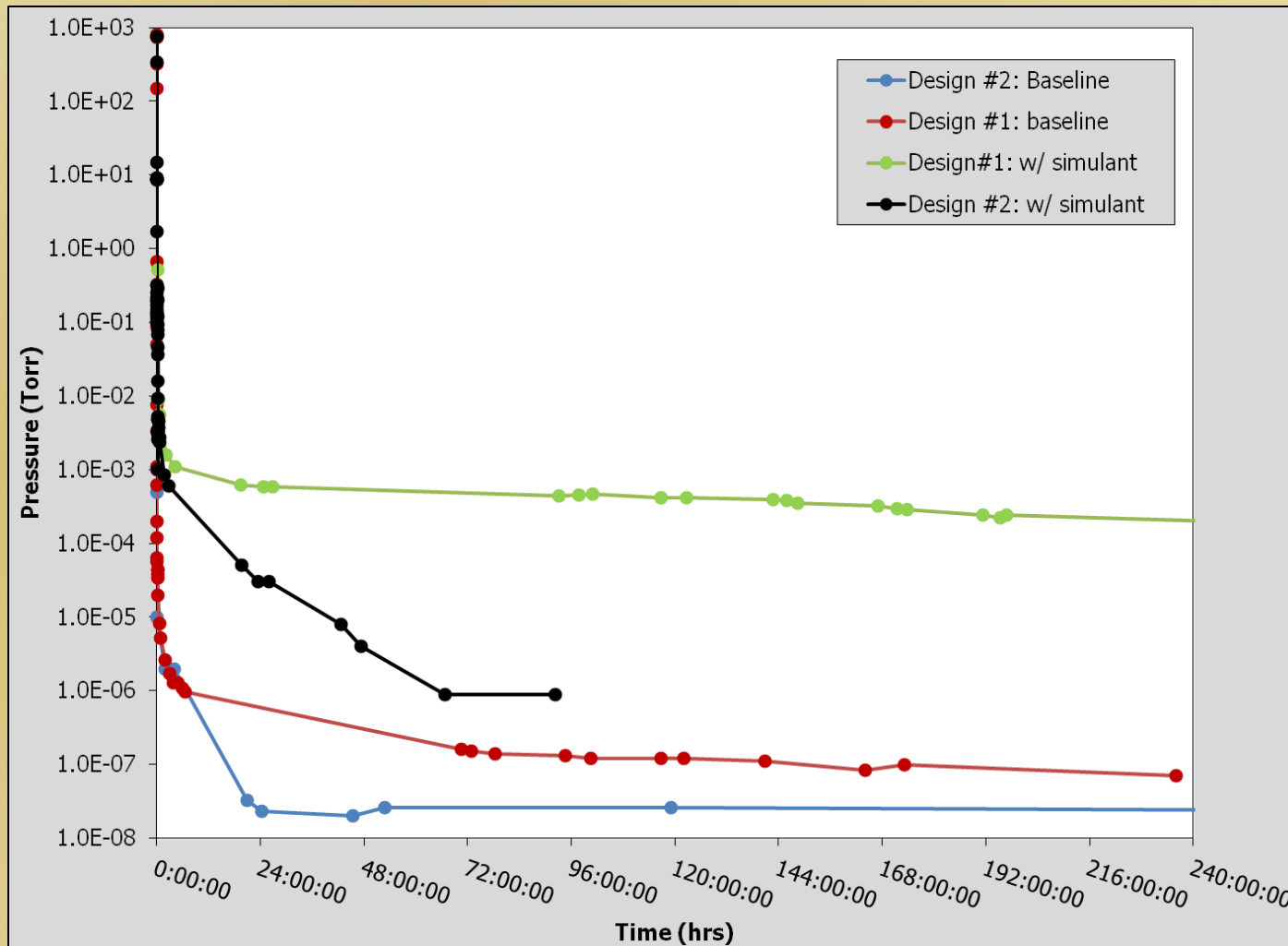
Initial Findings:

- Exposure to high vacuum results in increased soil strength
 - Attributed to increase in frictional and interparticle forces.
- Decrease in soil density when prepared under vacuum
 - Supports increase in frictional and interparticle forces under vacuum
 - Attributed to formation of honeycomb soil structure

Lessons Learned and Limitations



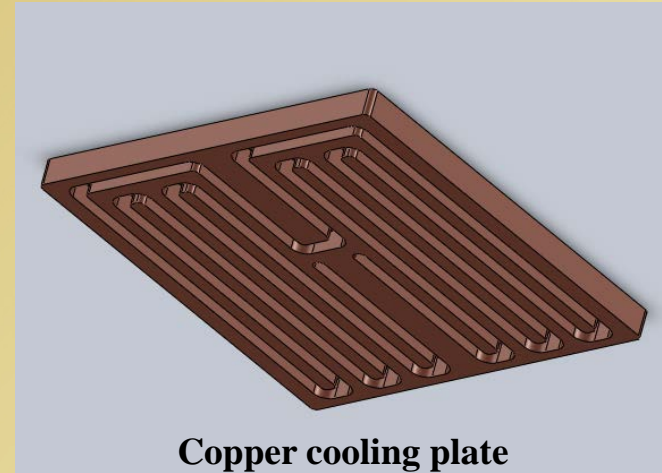
Improvements in Vacuum Performance



Future Improvements

Temperature Control:

- Refrigerated temperatures
 - Continuous flow of LN_2 through copper contact plate
 - Placed directly below OFHC copper soil bin
- Elevated temperatures:
 - 110 VAC halogen quartz substrate heat lamp
 - Temperatures measured using type T thermocouples



Copper cooling plate



Quartz heat lamp

Future Testing

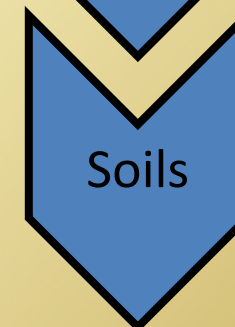
| Plate Sinkage Tests | | | | | | | | | |
|------------------------|---------------------------|-----------------|--------------|---------------------------|-----------------|--------------|---------------------------|-----------------|--------------|
| | Small Plate Size: | | | Medium Plate Size: | | | Large Plate Size: | | |
| | LN ₂ Cooled | Ambient Temp | Heat Lamp | LN ₂ Cooled | Ambient Temp | Heat Lamp | LN ₂ Cooled | Ambient Temp | Heat Lamp |
| Loose | | | | | | | | | |
| Medium | | | | | | | | | |
| Dense | | | | | | | | | |
| Cone Penetration Tests | | | | | | | | | |
| | Small Cone Size: | | | Medium Cone Size: | | | Large Cone Size: | | |
| | LN ₂ Cooled | Ambient Temp | Heat Lamp | LN ₂ Cooled | Ambient Temp | Heat Lamp | LN ₂ Cooled | Ambient Temp | Heat Lamp |
| Loose | | | | | | | | | |
| Medium | | | | | | | | | |
| Dense | | | | | | | | | |
| Shear Bevameter Tests | | | | | | | | | |
| | Small Annulus Size: | | | Medium Annulus Size: | | | Large Annulus Size: | | |
| | LN ₂ Cooled | Ambient Temp | Heat Lamp | LN ₂ Cooled | Ambient Temp | Heat Lamp | LN ₂ Cooled | Ambient Temp | Heat Lamp |
| Loose | | | | | | | | | |
| Medium | | | | | | | | | |
| Dense | | | | | | | | | |



- Plate-Sinkage
- Cone Penetration
- Shear Bevameter



- End effector size
- Temperature
- Soil preparation
- Pressure



- JSC-1A
- NU-LHT-2

Summary and Conclusions

- There is need for a device capable of simulating the lunar environment for the evaluation of soil deformation under surface loading.
- The effect of vacuum, temperature, density, and gravity on the strength of mare and highlands lunar soil simulants is being investigated.

Acknowledgements

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